4.2 Comparison of GOES-8 Imager and Sounder ST Retrievals to Ground Truth

To help determine the accuracy of the GHCC Imager and Sounder ST retrievals, comparisons were made to ground truth data. The ARM site in Oklahoma provides comparisons over land, and buoys provide data for SST comparisons. As previously mentioned, there are several factors to consider when comparing a ground measurement to a satellite area measurement. Because of these factors, including differences in footprint size, viewing angle, retrieval time, and in the case of SSTs depth of measurements, discrepancies between the ground and satellite retrievals should be expected. An additional comparison to the ARM site data including GOES-8 and GOES-11 retrievals is included in Section 4.3.2.2.

4.2.1 Comparisons to the ARM Site

For each of the case study periods, comparisons were made to ARM data for one or more days. An additional day, 11 June 2001, was included to help study the seasonal relationship between the ARM and satellite data. Recall that the ARM site has a down-looking Infrared Thermometer (IRT) that measures the radiating temperature of the ground surface (i.e., skin temperature). The IRT is positioned 25 m above the ground in a wheat field and provides measurements of the equivalent blackbody brightness temperature within the 10-12 μm atmospheric window, assuming an emissivity value of 1.0 (see Section 3.5). Satellite retrievals at single pixel and 3x3 averaged resolutions are compared to the ARM data. The resolution of the 5x5 averaged retrievals is too coarse to compare to a point measurement. For the January case there were several days with sufficient data to make comparisons, and thus averages of the differences between the

GOES and the ARM data and the hourly tendencies are presented. For the other case days, the differences and tendencies are computed from the single day shown for single pixel retrievals.

Figure 4.12 contains comparison plots for the following case study days: 18 September 2000 (a), 24 January 2001 (b), 13 April 2001 (c), and 11 June 2001 (d). The plots in Figure 4.12 display the relationship between the ARM data and the GOES Imager and Sounder ST retrievals. It can be seen that there are significant differences between the satellite and the ground measurements at certain times, and also close agreement at other times. Previous comparisons have been presented by Suggs et al. (2000) for cases on 18 August 1999, and 1 September 1999, and these results correlate well with the results presented here.

The differences between the satellite retrievals and the ARM measurements exhibit a seasonal relationship. For all seasons except summer, both the Imager and the Sounder retrievals reach a higher daily maximum temperature and are generally warmer for several hours than the ARM values. The GOES retrievals normally begin the day (at 1145 UTC) cooler than the ARM values, steadily become warmer than the ARM values during midday, and finish the day cooler than the ARM values. Seasonal changes are also occurring, with the September case showing the closest agreement between the GOES and ARM values, the January case showing large differences (both positive and negative) at different times throughout the day, and the April case showing large differences during the midday hours. In general, the GOES retrievals during the spring, fall and winter seasons exhibit a larger diurnal temperature range than the ARM values.

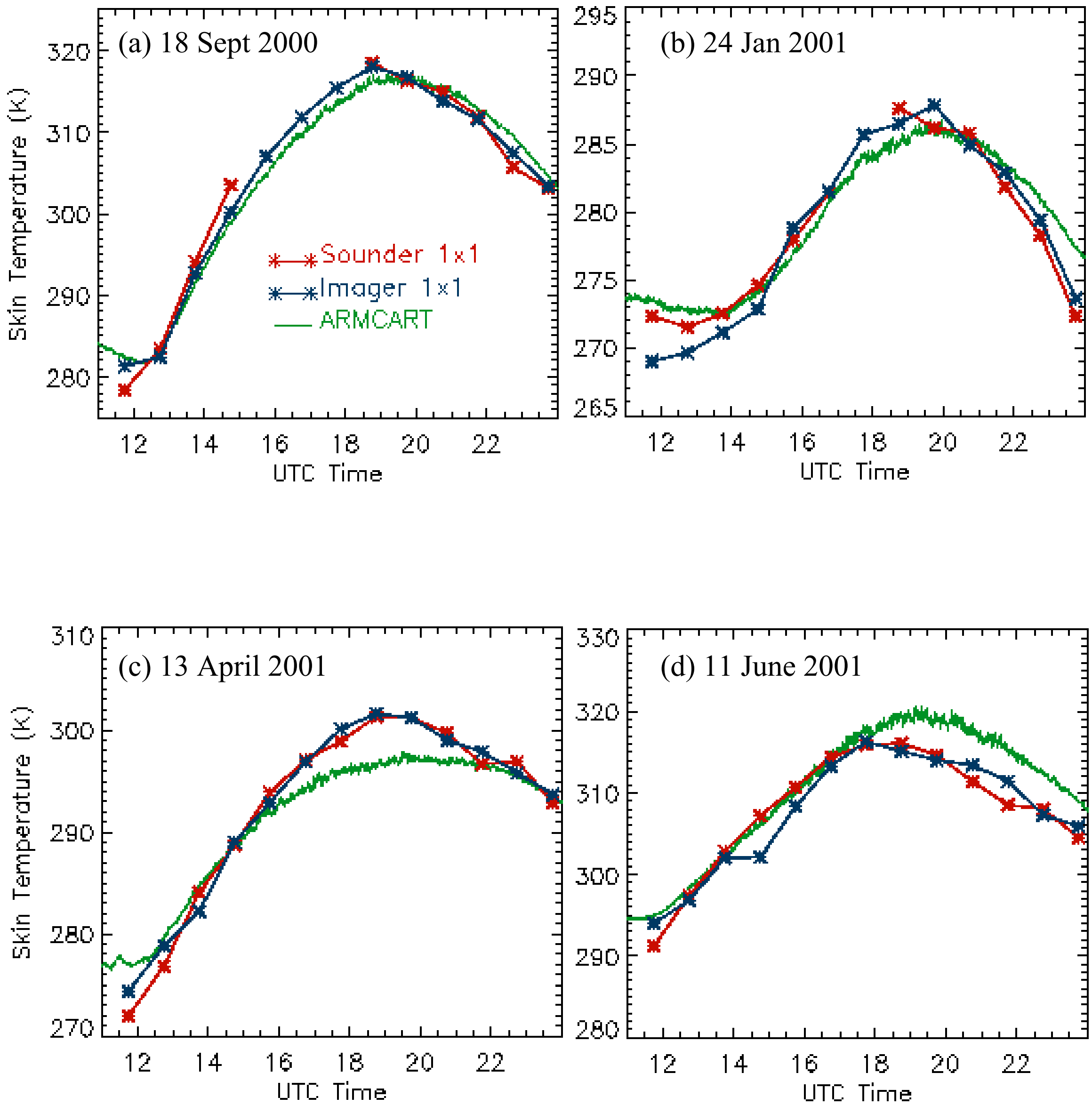

Figure 4.12 Single pixel Imager and Sounder ST point retrievals compared to ARM data.

During the summer season, this relationship changes. The June case presented in Figure 4.12 (d) and the two cases presented by Suggs et al. (2000) all show the ARM values displaying the maximum daily temperature. For the summer cases, the GOES and ARM values are very similar during the 1145-1745 UTC time frame, and then the ARM data becomes significantly warmer.

The seasonal variation of the differences between the GOES retrievals and the ARM measurements may be a result of several factors. First, one or both of the instruments may have calibration errors that change with the seasons, although it is unknown if an instrument bias exists, and if so if it is caused by the satellite and/or the IRT. Varying amounts of solar heating on the instruments may cause calibration errors. Second, the PSW algorithm may be producing a seasonal bias. The most likely cause of an algorithm bias is an incorrect surface emissivity assumption. However, this error source can also be associated with the IRT because the determination of ARM measurements also assumes a constant emissivity value. As previously noted, emissivities for the ARMCART region for summer are estimated to be 0.98, but for the winter season are estimated to be 0.966 (Faysash and Smith 2000). Since both the PSW algorithm and the determination of ARM values assume fixed emissivity values of 0.98 and 1.00 respectively, errors from both methods are expected. Third, the differing viewing angles of the two instruments and the changing solar zenith angle may be causing differences between the radiation amounts sensed by the satellite and the IRT. The IRT looks straight down upon the ARM location, but the viewing (zenith) angle between GOES-8 and the ARM location is approximately 48 ^{o}. The positions of the instruments remain constant, but the solar zenith angle changes throughout the year.

During the summer months insolation at the ARM location reaches its maximum intensity, and this is also the time period when a significant difference in the relationship between the GOES and ARM values occurs. As the sun's intensity decreases in the fall, the relationship changes and the GOES retrievals exhibit a larger diurnal range. It appears that during months when the solar and GOES satellite zenith angles are closer together than the solar and IRT zenith angles, the GOES instruments produce higher temperatures during the warmest time of the day.

The overall differences between the GOES and ARM ST values can be associated with the large differences in footprint size and viewing angle differences. The satellite is receiving radiation from a much larger area than the IRT and differences between the temperatures of these two regions can be expected. The bias between the GOES retrievals and the ARM values ranges from 3 to –3 K for the January case (average values), 4 to –3 K for the September case, 5 to –5 K for the April case, and 0 to –5 K for the June case. With respect to the ARM data, there is not an obvious choice between the Imager and the Sounder for the most accurate product. In some cases, such as 1245-1545 UTC on June 11, the Sounder product is closer to the ARM values. But in other cases, such as 2145-2345 UTC for the January case, the Imager product is closer to the ARM values.

Using a total of 11 case days representing all of the seasons, the scatter plots in Figure 4.13 were generated. The four plots in Figure 4.13 show the relationship between the ARM ST values and the GOES Imager and Sounder single pixel and 3x3 averaged retrievals. The correlation coefficients for each dataset are also provided. The plots indicate for all four datasets good agreement between the ARM and GOES data with

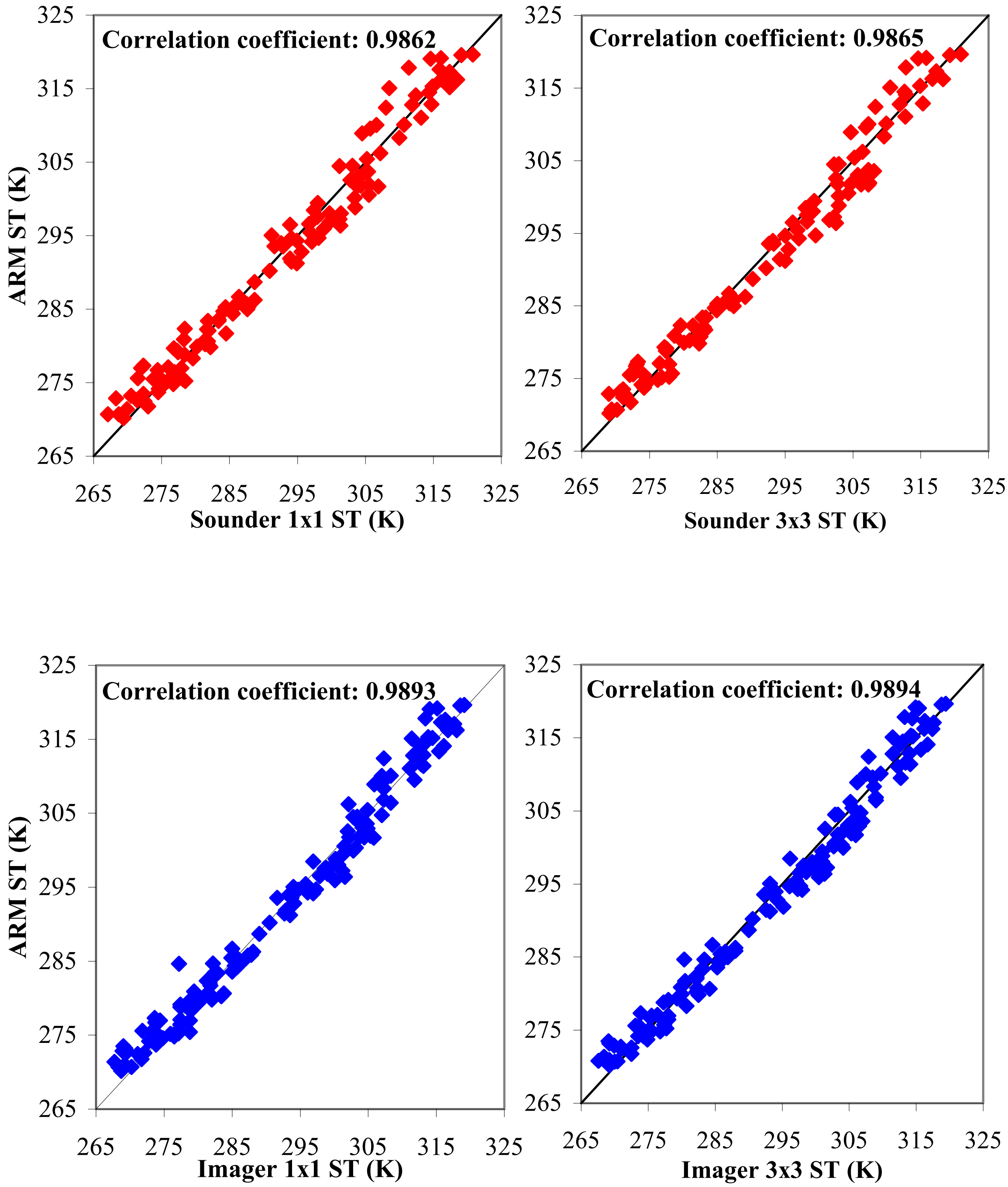

Figure 4.13 Scatter plots of GOES Sounder (top panels) and Imager (bottom panels) single pixel (left panels) and 3x3 averaged (right panels) ST retrievals versus ARM ST values.

correlation coefficients larger than 0.98. The plots also indicate the general pattern noticed in Figure 4.12, with the GOES data slightly cooler in the early morning hours (cooler temperatures), slightly warmer during midday (temperatures ranging from 285 K to 305 K), and cooler during summertime afternoon hours (warmer temperatures). The 3x3 averaged retrievals for both the Imager and Sounder have slightly higher correlation coefficients than the corresponding single pixel retrievals, suggesting that averaging removes noise contamination but retains the absolute magnitude of ST. The Imager correlation coefficients at 0.9893 and 0.9894 for single pixel and 3x3 averaged retrievals, respectively, are slightly higher than the corresponding Sounder values of 0.9862 and 0.9865. The numbers suggest, with respect to the ARM data, that the Imager provides more accurate retrievals than the Sounder.

Comparisons of the hourly tendencies are also made. Figure 4.14 presents the average tendencies for the January case, and the single day computed tendencies for the three other cases. Since the morning tendencies are assimilated into the forecast model in some of the GHCC application activities (Lapenta et al. 1999; Suggs et al. 2001), these comparisons help to determine the accuracy of the data input to the model. For the January case, there is close agreement between the ARM and GOES tendencies during the early morning hours. However, as the day progresses the differences between the ARM and the Imager and Sounder tendencies become larger (up to 1.5 K/hr). For the single day comparisons, agreement is generally within 2 K/hr (with the exception of the 1245 UTC tendency for September 18 when possible cloud contamination or calibration errors at 1145 UTC produced a cool mean temperature) for the September and June examples. The April case shows poor agreement at many times, but this is a partly a

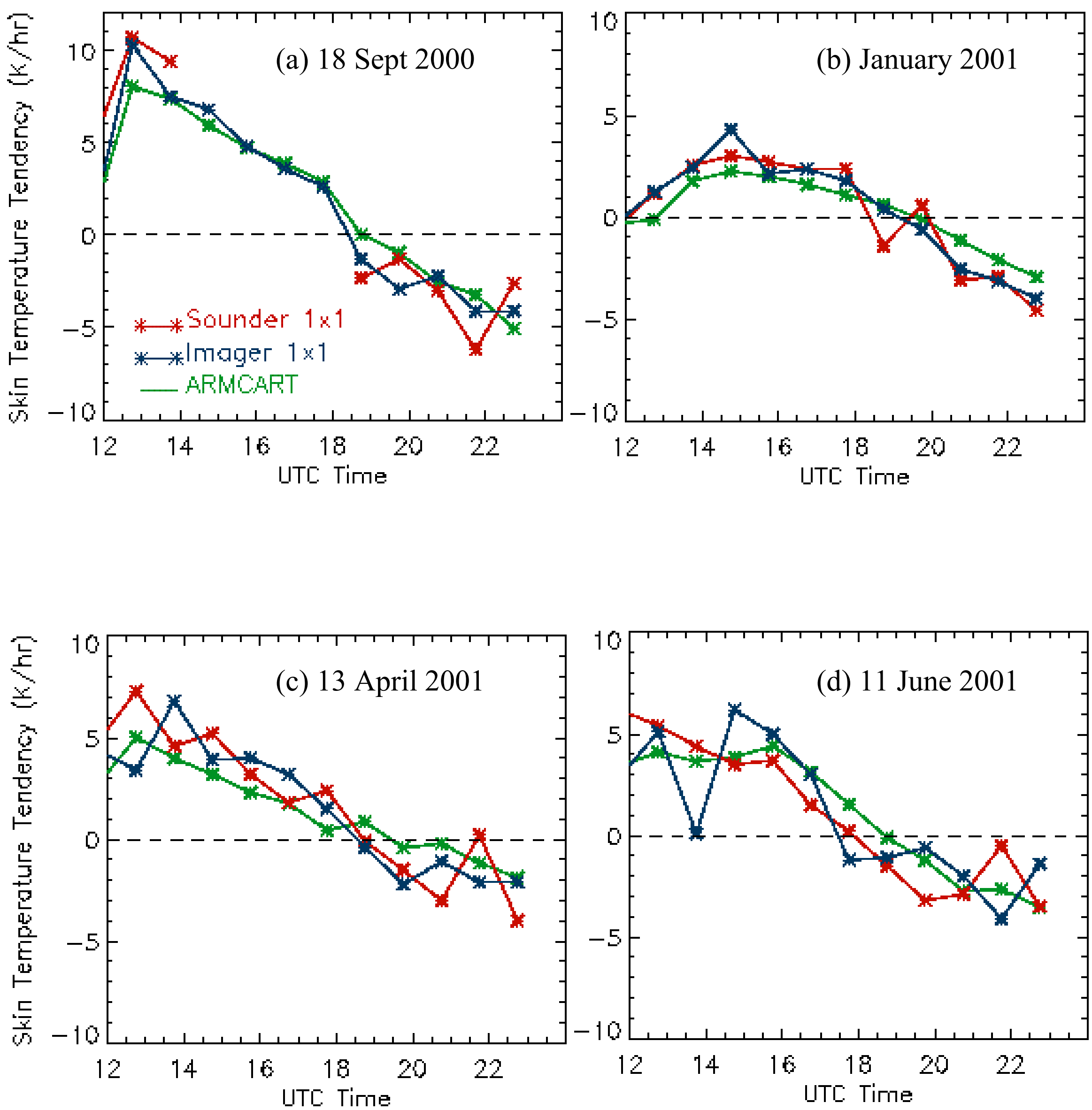

Figure 4.14 Hourly ST tendencies of single pixel Imager and Sounder retrievals at the ARM site.

result of possible cloud contamination. The tendencies computed from the Imager and Sounder agree fairly well with the pattern produced by the ARM tendencies, with discrepancies resulting from differences in footprint size, viewing angle, and inaccurate surface emissivity values. Again, there is no clear-cut choice between the Imager and the Sounder for the most accurate product in terms of ST hourly tendencies.

In summary, it is difficult to determine the accuracy of the GOES retrievals because of the seasonal variation of the bias between the ARM values and GOES retrievals. The large difference in footprint size and the differing viewing angles also make direct comparisons between the two results difficult to analyze. However, the GOES retrievals have been found to produce similar tendencies and magnitudes to the ARM values. Retrievals averaged from 3x3 pixel boxes produce smoother curves than their single pixel counterparts, therefore suggesting noise reduction. It is therefore recommended that averaged retrievals (Imager or Sounder) be used at single pixel spacing. To further determine the absolute accuracy of GHCC Imager and Sounder ST retrievals, comparisons to additional satellite products need to be performed. Future work will involve comparisons to the LST product derived from data from the MODIS instrument on the EOS satellites. By comparing to other satellite derived products, many of the factors contributing to errors and differences between the values can be removed.

4.2.2 Comparisons to Buoy Data

Comparisons to buoy SSTs were made for all the case studies, but only two examples are presented here because of the inconclusive results found. The SSTs produced using the PSW algorithm represent the actual surface temperature of the water, whereas the buoys measure the water temperature below the surface (for both examples presented here, the buoy SST is measured at 0.6 m below the water) and these differences can cause significant variations in temperature (Wick et al. 1999). In addition, the satellite is receiving a signal from a large footprint area compared to the point measurement of the buoys. These factors, together with the striping and noise errors, make analysis of buoy and GHCC GOES retrievals difficult to interpret. Comparison to other satellite derived SSTs may also provide uncertain results, since many of the satellite SST retrievals are produced by regressing to buoy SSTs.

Plots of SSTs derived from GOES-8 Imager and Sounder single pixel resolution retrievals compared to the water and air (measured 4 m above sea level) temperatures measured from buoys 42019 (September 30, 2000) and 42039 (January 24, 2001) are shown in Figure 4.15(a) and (b), respectively. Also included on these plots are the brightness temperatures from the two Imager and the two Sounder split window channels utilized by the PSW technique.

As expected, both the Imager and Sounder SST retrievals are for most cases warmer than the buoy SST and air temperatures. In addition, the Sounder retrievals are on average warmer than the Imager retrievals, suggesting either a warm Sounder bias or a cool Imager bias. By studying additional days, it appears that the GHCC retrievals on average exhibit an enhanced diurnal warming and cooling pattern compared to the buoy

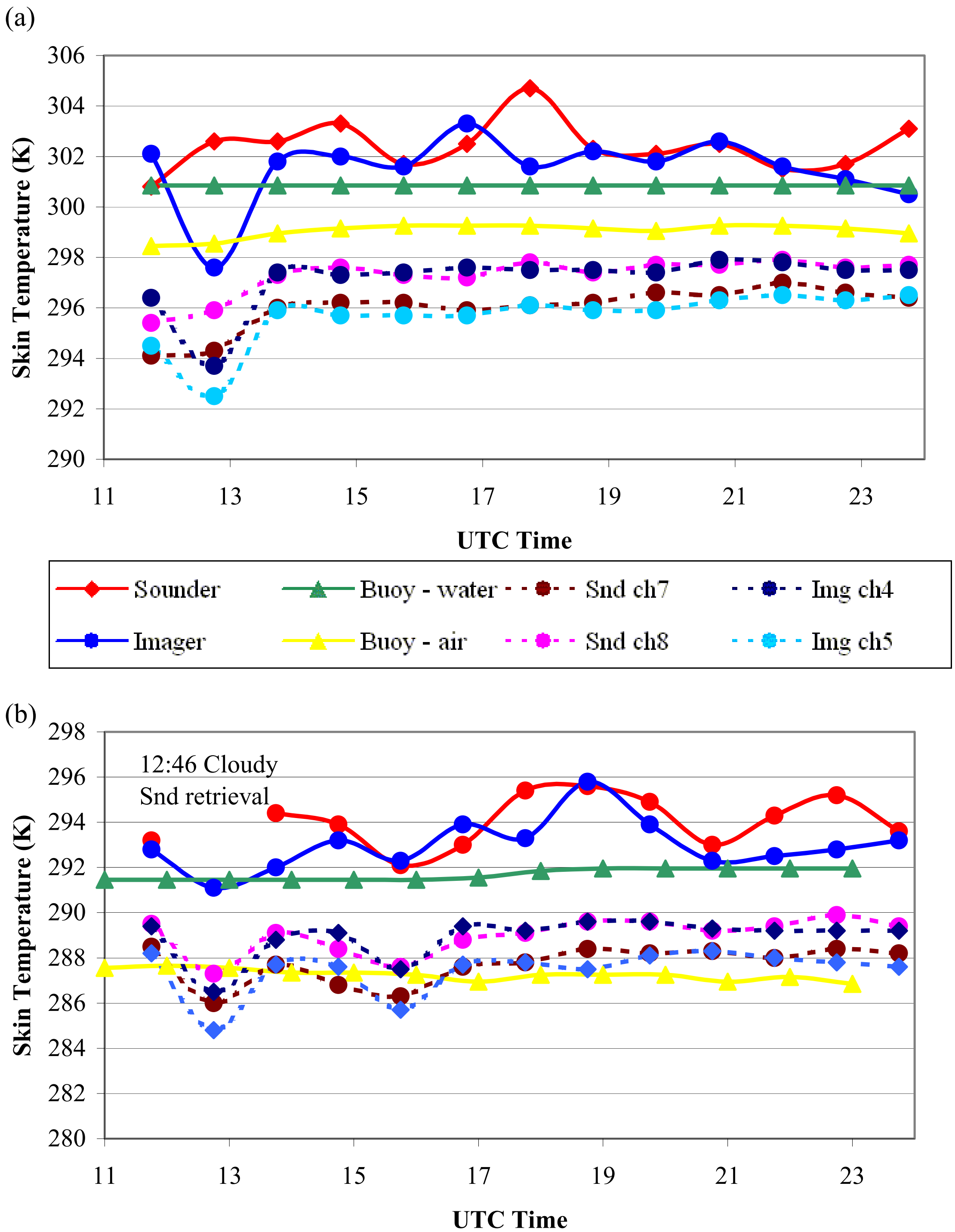

Figure 4.15 SSTs from GOES-8 Imager and Sounder single pixel resolution retrievals, brightness temperatures from the Imager and Sounder split window channels, and water and air temperatures from buoy 42019 on September 30, 2000 (a) and from buoy 42039 on January 24, 2001 (b).

SSTs. The satellite retrievals can be expected to show more diurnal warming and cooling than the buoy SSTs because the satellite is measuring the temperature from the surface, whereas the buoys are measuring the temperature beneath the water.

A comparison of the Imager and Sounder retrievals to the buoy values (Figure 4.15) reveals large variations of the satellite retrievals from one time to the next, compared to the almost constant buoy water and air temperatures. To determine if these variations are algorithm or instrumentation related, the brightness temperatures for the split-window channels used in the algorithm were included on the plots. Brightness temperatures from the Imager channels 4 and 5 and the Sounder channels 7 and 8 show significant variations with time. The plots of the GOES SST retrievals in Figure 4.15 tend to follow the pattern of their corresponding brightness temperatures. When the brightness temperatures show a significant decrease or increase, the SSTs also exhibit the same variation. However, the variations differ at some retrieval times. For example, at 1945 UTC on January 24, the Imager SST has decreased by 2 K from the previous hour. The corresponding channel 4 brightness temperature remains constant and the channel 5 brightness temperature shows a slight increase. The difference between the two brightness temperatures is a measure of differential water vapor absorption within the atmosphere. As the difference between the channel 4 and channel 5 brightness temperatures decreases, the amount of water vapor detected in the atmosphere decreases. The less water vapor detected, the closer the skin temperature retrieval will be to the cleanest split window channel (channel 4) brightness temperature. Therefore, when the difference between the two brightness temperature values decreases, even if one or both show an increase, the skin temperature retrieval may show a decrease. Inclusion of the brightness temperatures within the comparison indicates that the errors are not completely algorithm related. The temporal changes in the satellite brightness temperature difference, real or due to errors, are causing much of the variation.

The brightness temperatures also help to suggest cloud contamination errors. For example, at 1245 UTC on January 24, the Sounder retrieval was determined to be cloudy, but the Imager retrieval was not. The brightness temperatures for all the channels show a significant decrease at this time, implying cloudy conditions, or at least partly cloudy within the pixel area.

In summary, comparisons to buoy SSTs on a case study basis are inconclusive in determining the accuracy of the GOES-8 Imager or Sounder ST products. The case study comparisons reveal that single pixel retrievals are influenced by a significant amount of noise, and averaging is required to reduce this noise, and that the variation in the retrieved ST values is mostly instrumentation not algorithm related. Because of the small diurnal temperature changes, the striping and noise influence is much more prominent in the ocean comparisons than seen in the ARM comparisons. The averaged retrievals reveal a small diurnal change as the surface of the water heats up and then cools down as a function of the absorbed insolation.